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A Further Look at the Prediction of Weapons Effectiveness in Suppressive Fire

by

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This research and literature review investigated the relationship between acoustic signatures of small-arms projectiles and the suppressive behavior which results from soldiers' perceptions of danger. Kinetic energy, which is associated with perceived loudness of passing projectiles, appears to be the primary physical property of projectiles that affects behavior under fire. The report is written for military personnel.

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Technical Report TR-79-A19

A FURTHER LOOK AT THE PREDICTION OF WEAPONS EFFECTIVENESS IN SUPPRESSIVE FIRE

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FOREWORD

The Fort Hood Field Unit of the Army Research Institute for the Behavioral and Social Sciences (ARI) provides support to Headquarters, TCATA (TRADOC Combined Arms Test Activity; formerly called MASSTER--Modern Army Selected Systems Test Evaluation and Review). This support is provided by assessing human performance aspects in field evaluations of man/weapons systems.

A war using modern weapons systems is likely to be both intense and short. US man/weapons systems must be effective enough, immediately, to offset greater numbers of an enemy. Cost-effective procurement of improved or new combat systems requires testing that includes evaluation of the systems in operational settings similar to those in which the systems are intended to be used, with troops representative of those who would be using the systems in combat. The doctrine, tactics, and training packages associated with the systems being evaluated must themselves also be tested and refined as necessary.

This report presents the results of an investigation originally designed to determine what aspects of the auditory signatures of passing projectiles are perceived as making the projectiles dangerous, resulting in suppressed behaviors. The report presents a review of the relevant literature, and examines kinetic energy as the primary physical property of projectiles that affect behavior.

ARI research in this area is conducted as an in-house effort, and as joint efforts with organizations possessing unique capabilities for human factors research. The research described in this report was done by personnel of the Human Resources Research Organization (HumRRO), under contract DAHC19-75-C-0025, monitored by personnel from the ARI Fort Hood Field Unit. This research is responsive to the special requirements of TCATA and the objectives of RDTE Project 2Q763743A775, "Human Performance in Field Assessment," FY 1978 Work Program.

A FURTHER LOOK AT THE PREDICTION OF WEAPONS EFFECTIVENESS IN SUPPRESSIVE FIRE

BRIEF

Requirement:

The work carried out in this study is that referred to in paragraph 2.2.23 of the Statement of Work dated 16 May 1977 under the title of "Suppression Research." The objectives of this effort were:

- To provide a review of the literature published since 1970 on fire suppression by small arms.
- To determine from information available what aspects of the acoustic signatures of projectiles contribute to their being perceived as dangerous and result in suppressed behaviors.

Procedure:

A field study conducted in the early 1970s produced a psychological rating of "perceived dangerousness" of a series of small arms fire events. A behaviorally anchored Suppression Index (SI) was also derived from a similar set of small arms fire events. It was concluded that the psychological scales were based almost solely on the subjects's reactions to the noises of the passing projectiles. However, no data on the acoustic signatures of the projectiles were obtained at that time. This effort was initiated as a literature review to determine whether data on acoustic signatures of the weapons employed were available, and if so, whether any aspect(s) of these signatures could be employed to "predict" the psychological scales. A review of the general literature on suppression was also conducted.

Principal Findings:

- Data on the acoustic signatures of projectiles down range from the weapon are extremely limited, and are not complete enough to be of any value in determining the relationship between signatures and the psychologically-derived Suppression Index and perceived dangerousness ratings.
- Kinetic energy, which is believed to be closely related to the perceived loudness of passing projectiles, appears to account for nearly 100% of the variance between weapons on both the Suppression Index and the perceived dangerousness ratings.
- Further research is needed to validate the findings relative to kinetic energy, and to better establish the mathematical relationship between miss distance, rate of fire, and psychological scales such as the Suppression Index.

Utilization of Findings:

Operations research analysts in attempting to play suppression in combat models have had to rely on intuition and fragmentary descriptions of behavior under fire to develop their models. As a result, the handling of suppression has been highly variable. The results of the analysis in this research should provide them with another tool to help refine computer models involving suppression play.

CONTENTS

Chapter 1

BACKGROUND

It has long been believed that most weapons, in addition to their casualty-producing capabilities, also have incapacitating psychological effects which may inaccurately reflect the actual threat. Earlier works dealing with these psychological effects[1,2,3,4,5] invoked the concept of fear. Essentially, all of these efforts were directed toward finding out which weapons were most feared by the respondents. Subjects queried included American, British, German, North Korean, and Communist Chinese soldiers. While these works did demonstrate that fear of a weapon and its casualty-producing capability were not perfectly correlated, only minimal information was obtained on the reasons for the observed discrepancies. Furthermore, as Terry[6] pointed out, the data obtained were strictly ordinal in nature with the scales typically ranging from most feared to least feared. In addition, the effects on the actual behavior of the individuals queried were not determined. In other words, it could not be determined whether these stated fears had any effect on the conduct or the outcome of a battle. Therefore, these earlier data are useful only as an aid in the formulation of hypotheses.

One of the behavioral results expected from fear of enemy weapons is the phenomenon called "suppression." The term suppression has long been a part of the Army's vocabulary. However, attempts to arrive at a precise definition have proven elusive.[7] Virtually all definitions of

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[1] J. Dollard. *Fear in Battle,* The Institute of Human Relations, Yale University, New Haven, Connecticut, 1943.

[2] H. Goldhamer, A. L. George, and E. W. Schnitzer. *Studies of Prisoner-of-War Opinions on Weapons Effectiveness (Korea)* (U), RM-733, Rand Corporation, Santa Monica, California, December 1951.

[3] L. A. Kahn. *A Preliminary Investigation of Chinese and North Korean Soldier Reactions to UN Weapons in the Korean War,* ORO-1-14 (FEC), Johns Hopkins University, 1952.

[4] L. A. Kahn. *A Study of Ineffective Soldier Performance Under Fire in Korea,* ORO-T-62 (AFFE), Johns Hopkins University, 1954.

[5] S. A. Stouffer, et al. *The American Soldier: Combat and Its Aftermath, Vol II,* Princeton, New Jersey: Princeton, University Press, 1949.

[6] R. A. Terry. *Toward a Psychological Index of Weapons Effectiveness. Part I: Field Studies,* Technical Report 1419-5, University of Oklahoma Research Institute, Norman, December 1964.

[7] L. A. Huggins, Jr. "A Simplified Model for the Suppressive Effects of Small Arms Fire," Masters Thesis, Naval Postgraduate School, Monterey, California, September 1971.

suppression attempt to relate the volume of fire of one force to a degradation of performance of the opposing force. For example, Winter and Clovis[8] define suppression as "...the causing of human reactions that reduce individual (unit) efficiency to fire, observe, and move." A Combat Developments Experimentation Command (CDEC) report[9] states that the TRADOC definition is "the degradation of specified combat activity for a particular period of time." According to Kinney,[10] "suppression is a short-term transient degradation in the combat performance of infantrymen. It is produced by their behavioral response to the lethality potential (risk) of impacting weapons that do not incapacitate them." The Ad Hoc Group on Fire Suppression[11] states that suppression is:

> ...a process which causes temporary changes in performance capabilities of the suppressee from those expected when functioning in an environment which he knows to be passive. These changes are caused by signals from delivered fire or the threat of delivered fire, and they result from behaviors that are intended to lessen risk to the suppressee.

Numerous other definitions have been given in the literature, but all of those located were very similar to the preceding examples. All of the definitions imply that suppression is temporary, i.e., it is not a result of physical incapacitation due to injury or death. They also imply that some aspect of performance must be adversely affected before a force or an individual can be said to be suppressed. The performances most frequently mentioned are those of observation, returning fire, and maneuvering. However, a broader view was taken by the Ad Hoc Group.

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[8] R. P. Winter and E. R. Clovis. *Relationship of Supporting Weapon Systems Performance Characteristics to Suppression of Individuals and Small Units*, TR 73/002, Defense Sciences Laboratories, Mellonics Systems Development Division, Litton Systems, Inc., Sunnyvale, California, January 1973.

[9] Project Team II, US Army Combat Developments Experimentation Command, and Braddock, Dunn, and McDonald Scientific Support Laboratory, Fort Ord, California. *Dispersion Against Concealed Targets (DACTS), USACDEC Experiment FC 023,* Final Report, July 1975.

[10] D. G. Kinney. *Suppression Analysis Technique* (U), unclassified version of paper presented to 33 MORS, Weapons Planning Group, Naval Weapons Center, China Lake, California, undated.

[11] US Department of the Army, Office of the Deputy Chief of Staff For Research, Development, and Acquisition, Washington, D.C. *Report of the Army Scientific Advisory Panel Ad Hoc Group on Fire Suppression,* ODCSRDA Form 11, 7 July 1975.

For example, they spoke of the suppression of command and control activities through electronic warfare. Obviously, loss of communications is likely to degrade performance in other areas, especially maneuvering. However, most other writers appear to take a narrower view and consider the degraded performance to be a direct result of behaviors resulting from fear of incapacitation.

It should be noted that the contemporary definitions of suppression attempt to deal with observables, i.e., behaviors, while the earlier works relied on a purely mental concept of fear. It should also be noted that these behavioral definitions objectively permit anchoring the ends of any suppression scale. If no decrement in *performance* can be observed (regardless of what individual members of a force may state about the intensity of their fears), suppression is rated zero. If all observable behavior is devoted solely to the minimizing of personal risk, suppression is said to be complete or 100%. In other words, if the fire intensity is such that an individual devotes his total effort to seeking greater cover, he is totally suppressed. Increases in fire power beyond this intensity cannot therefore increase suppression. Despite these objectively defined end points, the measurement of the degree of suppression along the scale has proven to be difficult and controversial. For example, given a known level of fire, is it possible to relate the degree of suppression of a force with extremely limited mobility, but with the ability to observe the enemy and return fire, to that of a force with the ability to observe and maneuver, but with a limited capability of returning fire? Most likely, in either case the ability to observe the enemy will be the last function suppressed. However, the absolute or even the relative importance of each of these functions is difficult to establish. Furthermore, the degree of suppression is also dependent upon the mission. If he is adequately protected and concealed, a soldier observing enemy movement may be hardly suppressed by enemy machinegun fire. Under the same conditions, the soldier whose mission is to advance on the enemy might well be totally suppressed.

It can be plausibly argued that at any given time, suppression is either total or nonexistent. For example, assume that an infantryman is in a foxhole observing the enemy and firing as enemy personnel reveal themselves. Movement at this time is not a part of his mission. Further assume that machinegun fire suddenly begins to rake the area. The soldier will undoubtedly duck into his foxhole and abandon attempts to observe, return fire, or move. That is, he will be completely suppressed. However, shortly after the machinegun fire ceases, he will again observe and fire on the enemy. In this sequence of events, the soldier will go from being virtually unsuppressed, to being totally suppressed, to being virtually unsuppressed again. Although not explicitly stated as such, this line of thinking probably led the CDEC team[12] to view suppression as the percentage of time an individual was

[12] Project Team II, *op. cit.*

unable to perform a specific assigned duty during a given period of time. If one is willing to assume that suppression is always either near 0 or near 100%, the "percent time suppressed" is a very reasonable measure of the degree of suppression. As can be seen, attempts to define, much less measure, the degree of suppression have been fraught with problems.

In all of the literature located, the authors agreed that suppression was a "temporary" phenomenon. However, the meanings attached to temporary were quite variable. Huggins,[13] reported on a CDEC study in which a target was said to be suppressed if two projectiles passed within two meters of the target within an .04 minute time interval. The duration of suppression was .06 minutes, but could be extended for .01 minute for each projectile that passed within two meters of the target while it was suppressed. Translating this into seconds, the minimum suppression time appears to be 3.6 seconds, which is incremented by .6 seconds for each additional round. Kinney[14] states that "suppression is a short-term transient degradation...," and defines "short-term" as being "in the order of tens of seconds." The Ad Hoc Group[15] points out that most suppression models use constant durations with suppression time running from 10 to 60 seconds. They question the use of these short periods by noting that in the recent Mideast War, a non-killing hit on the turret would cause a tank crew to stop activity for as much as 8 to 10 minutes. Unfortunately, actual combat data relating type and intensity of fires, the range of individual behaviors, and the duration of suppression are practically nonexistent. Therefore, the current authors view these time estimates as merely "best guesses." Most attempts to determine the duration of suppression have been based on retrospective interviews of combat-experienced personnel. Variations in combat situations such as the types and intensity of fires, the amount and kind of protection, the relative size of the opposing forces, and the experience and personalities of the individuals make it extremely difficult to systematically compare the recollections of different individuals. Furthermore, the validity of retrospective data is always suspect, particularly when any behaviors reported could reflect adversely on the interviewee. Therefore, it is not surprising that the literature reports great variability in the estimated duration of suppression.

To further complicate the issue, investigators have stated that suppression can be either "reasoned" or "unreasoned."[16] Reasoned suppression is said to occur when an individual attempts to optimize the tradeoffs between his personal protection and the accomplishment of the mission. Unreasoned suppression is said to occur when the risk-reduction behavior is far out of proportion to the actual threat. Unfortunately, what seems reasoned to one may seem foolhardy to another, and

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[13] Huggins, *op. cit.*

[14] Kinney, *op. cit.*

[15] US Department of the Army, *op. cit.*

[16] Winter and Clovis, *op. cit.*

vice versa. As the Ad Hoc Group[17] pointed out, "reasoned performance" in a given situation must be defined. How does the individual weigh his personal survival against the importance of the mission? How does one realistically assess personal risk? Can the reasonableness of performance at any given time be evaluated in terms of percent casualties experienced? These and other similar questions must be answered before criteria for reasonableness can be determined. At first, it might seem that an individual who performed as if suppressed while not under fire was exhibiting "unreasoned performance." However, this is not necessarily the case. Suppression can be divided into two categories--reactive and threat.[18] Reactive suppression results from being taken under fire. Threat suppression occurs when there is a high *probability* of being taken under fire (especially if protection is poor). Kinney[19] refers to this latter kind of suppression as "anticipatory" suppression. He states that anticipatory suppression is based on a future risk, while reactive suppression is based on a current risk.

Naylor[20] implies that weapons designers need more information than is supplied by definitions of suppression alone. The weapons designer needs to know the particular characteristics of a weapons system which are associated with specific behavioral responses. The earlier data generally indicate the proportion of respondents who reported fear of each of a particular set of weapons. Data on why the weapons were feared tends to be sparse. Naylor presents data from an earlier study indicating that such things as accuracy of fire, lack of warning, rapidity of fire, noise, and a lack of defense were typically stated as reasons for fear of various weapons. Yet, inconsistencies existed. For example, noise was a frequently cited reason for fear of dive bombers. However, noise did not appear to be a major factor in a fear of artillery shelling. Naylor's thesis is that we know virtually nothing about the separate or combined contributions of weapons characteristics in terms of their effects on human behavior. In his point of view, the problem is:

> ...really one of assessing the effect of a particular stimulus, which is occuring under a particular set of circumstances or within a particular environment, upon the behavior of an individual or a group of individuals.

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[17] US Department of the Army, *op. cit.*

[18] *Ibid.*

[19] Kinney, *op. cit.*

[20] J. C. Naylor, et al. *Proceedings of the First Symposium on the Psychological Effects of Non-Nuclear Weapons, Volume I*, University of Oklahoma Research Institute, Norman, April 29, 1964.

Stated somewhat differently, we will be able to effectively assess the psychological effects of weapons, or, to predict the responses to new weapons systems only when we are able to quantify both the stimuli associated with weapons and the responses obtained from use of these weapons.

At this juncture, it might be well to examine why it is so important to predict the behavioral responses to the visual and auditory signatures of weapons. One reason, as Naylor pointed out, is that such information might be useful in designing future weapons systems. However, it is also critical that we know what responses should be expected to employment of existing weapons systems. Many decisions concerning the makeup and deployment of our armed forces are based on computer simulations of hypothetical future engagements. The results obtained are only as good as the input data and assumptions underlying the models used. Obviously, if suppression does in fact exist, then it should be played as part of the engagement. However, as was pointed out earlier in this discussion, attempts to model suppression heretofore have been based on "best guesses" of the modelers. The variability in how suppression is handled in the different models indicates an urgent need for better data. Inaccurate modeling of suppressive effects can only lead to less accurate decisions. Therefore, any data which improve the modeling efforts should be extremely useful. This research was initiated as an attempt to relate stimulus characteristics of *selected small arms* to psychologically scaled values of indexes of suppression and perceived dangerousness of each of these weapons. Hopefully, the results can be employed to improve combat models, and, as Naylor has suggested, provide useful information to weapons designers.

Chapter 2

RESEARCH PROBLEM AND LITERATURE REVIEW

Research Problem

Introduction. Kushnick and Duffy[1] reported on a series of studies aimed at relating the characteristics of small arms to their suppression capability. In an effort to generate hypotheses, they completed an extensive review of the literature and conducted interviews with a large number of combat veterans. They concluded that miss distance, caliber, and rate of fire were the primary determinants of suppressive capability. Based on their analyses of the literature and interview data, they designed a series of experiments to verify their hypotheses. In one of these studies, observers were placed in a pit and given a scenario describing a hypothetical battle situation in which they were to imagine they were involved. Small arms were then fired over the pit from a range of 150 meters. Varying lateral miss distances were employed. Miss distance was controlled by aiming the weapons at a series of targets emplaced on the opposite side of the pit from the weapons. After each sequence, observers were asked to select one of seven alternative statements which would best describe their behavior under these circumstances on an actual battlefield. These alternatives are shown in Table 2-1.

These alternatives were later scaled in terms of the amount of suppression each represents through the use of Delphi techniques. These scaled values are shown in the second column of Table 2-1.

Following this, each respondent's reply to each situation was assigned the appropriate scale value, and the values were averaged across respondents and conditions to develop a suppression index for each weapon. The weapons and their scale Suppression Index (SI) values are shown in Table 2-2.

In another experimental study, data on perceived dangerousness of live fire events were obtained in the same physical environment described above. However, rather than a behavioral type scale such as was used in developing the Suppression Index, dangerousness was rated on a simple 7-point scale. The anchor points were "no personal danger" and "maximum dangerousness." It was concluded that the major factors producing a perception of dangerousness are the loudness of passing

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[1] S. A. Kushnick and J. O. Duffy. *The Identification of Objective Relationships Between Small Arms Fire Characteristics and Effectiveness of Suppressive Fire*, TR 72/002, Final Report, Mellonics Systems Development, Litton Industries, Sunnyvale, California, 3 April 1972. (For a less technical version, see G. M. Gividen, "Weapons Effectiveness and Suppressive Fire," in *Proceedings*, 13th Annual US Army Operations Research Symposium AORS XIII, 29 Oct. - 1 Nov., 1974, Fort Lee, Virginia, Vol II, pp 503-513.

Table 2-1. Response Alternatives to Fire Events

Response Alternative	Delphi Scale Value
A. Take cover as best I could, but wouldn't be able to observe or fire on the enemy at all.	100
B. Take cover as best I could and would be able to observe the enemy occasionally, but wouldn't be able to fire at the enemy at all.	90
C. Take cover as best I could and would be able to observe the enemy continuously but wouldn't be able to fire at the enemy at all.	80
D. Take cover as best I could, and would be able to observe the enemy occasionally and fire at the enemy occasionally.	59
E. Take cover as best I could, and would be able to observe the enemy continually and fire at the enemy occasionally.	34
F. Take cover as best I could, but would be able to observe the enemy continually and place continuous fire on the enemy.	17
G. Would continue doing what I had been doing before the incoming fire and wouldn't worry about getting better cover.	0

rounds, the proximity of passing rounds, and the volume of fires.[2] Since the proximity of passing rounds and the rates of fire were held constant, it was concluded that the loudness of the passing rounds was the primary determinant of differences in perceived dangerousness in the experiment. Loudness was believed to be closely related to the kinetic energy of the projectiles as they passed near the subjects. However, the relationship between kinetic energy and perceived dangerousness proved to be curvilinear. The tabled data, adapted from Kushnick and Duffy, are shown in Table 2-3. From this result, it can be concluded that either (a) kinetic energy is not linearly related to perceived loudness, or (b) other factors in the acoustic signature are at play in determining perceived dangerousness. It is interesting that the two weapons which caused the curvilinearity are those with the highest (XM645 flechette) and lowest (.45 caliber) velocities. It is conceivable that the frequency spectrum and duration of the sounds from these projectiles at the extremes of velocity may affect their perceived dangerousness above and beyond the loudness component. However, Kushnick and Duffy made no attempt to relate these characteristics to perceived dangerousness. In fact, no data on projectile signatures were obtained during the study. However, with interest in suppression still high, it was felt that it would be useful to determine whether or not other aspects of the auditory signatures of the projectiles could be employed to improve the prediction of perceived dangerousness. Therefore, this effort was initiated to (a) determine what information on the auditory signatures was available or could be made available, and (b) to determine whether these data could be employed to improve the prediction of the psychologically-derived measures by physical measures.

Approach. As originally conceived, this effort was to be conducted in two phases. The initial phase was to be an attempt to locate data on the auditory signatures of the small arms projectiles employed in the Kushnick and Duffy studies. However, it was also deemed advisable to accomplish an update review of the literature to determine if any relevant work had been accomplished since the very complete review reported by Kushnick and Duffy. A portion of the material reviewed was employed in the background discussion in Chapter 1. Additional discussion of the literature will follow in the next major section of this chapter.

The second phase of the effort was to be an attempt to relate the auditory signature data of the small arms projectiles to the psychologically-scaled values of suppression and perceived dangerousness. It was determined that only available data on auditory signatures should be used at this time. An attempt to obtain new data was viewed as too costly. The instrumentation required for obtaining accurate data on

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[2] Another study was conducted to determine the suppressive effect of the visual signatures of impacting rounds. While these signatures were related to suppression, they did not play a part in the experiments in which the Suppression Index and the Perceived Dangerousness Index were derived.

Table 2-2. Suppression Scale Scores

Weapon	Mean SI	Standard Deviation
XM19	29.82	23.41
M16	35.10	22.83
AK47	36.44	24.84
M60	43.27	23.72
Caliber .50 MG	60.99	30.77

Table 2-3. Relationship Between Kinetic Energy (KE) and Perceived Dangerousness

Projectile	KE x 10^{-8}	Perceived Dangerousness Index
Caliber .50	27.79	47
M60	3.63	41
AK47	2.20	39
M16	1.33	37
Caliber .45	.93	27
XM645	.94	23

auditory signatures is highly sophisticated (e.g., see Garinther and Moreland[3]), and simply not available. In addition, duplicating the conditions under which Kushnick and Duff's subjects perceived the passing rounds would also be difficult. Therefore, it was felt that the available data should first be analyzed. If these data showed significant promise for predicting the psychological scales, then a determination would be made as to the desirability of obtaining new and more complete data on the auditory signatures.

Unfortunately, all of the data desired could not be located. Nevertheless, some further analysis of Kushnick and Duffy's data seemed warranted. The results of this analysis are presented in Chapter 3.

Discussion of the Literature

The primary source of the literature obtained was the Defense Documentation Center (DDC). However, personnel at the Human Engineering Laboratories (HEL), Test and Evaluation Command (TECOM), Picatinny Arsenal, the Army Environmental Hygiene Agency (AEHA), and the Ballistic Research Laboratories (BRL) were also contacted in an effort to insure completeness. The emphasis in the searches was on the more recent literature; that is, literature published since the review by Kushnick and Duffy. However, because of their perceived high relevance, a number of documents referred to by Kushnick and Duffy were also obtained. An attempt was also made to limit the documents obtained to those which dealt with the suppression of infantry units, and/or suppression resulting from the use of small arms. A considerable portion of the effort was also invested in the search for auditory signature data of small arms. The search in DDC was complicated by the inconsistency in the use of key words. For example, there were over 40 entries for the M16 rifle and associated equipment. While it was possible through proper coding of entries to form some groups for the searches, the process was still quite tedious. For example, by use of proper input codes, it was possible to retrieve information on all documents having key words such as M-16, M-16 rifle, M-16 rifles, M-16 gun, and M-16 guns. However, separate searches had to be made for documents with key words such as M 16 and M16. Also, in order to retrieve documents related to suppression, a variety of key words such as suppression, fire suppression, and weapons systems effectiveness had to be employed. All in all, approximately 100 combinations of key words were employed in the DDC searches.

The general literature on suppression can be divided into three broad categories. The older documents were primarily reports of interview and/or questionnaire studies. The newer documents dealt primarily

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[3] G. R. Garinther and J. B. Moreland. *Transducer Techniques for Measuring the Effect of Small-Arms Noise on Hearing*, Technical Memorandum 11-65, US Army Human Engineering Laboratory, Aberdeen Proving Ground, Maryland, July 1965.

with field experiments or the development of models for use in gaming. However, few of the reports reviewed were "pure" in that they fell exclusively into one of the three categories. Also, many of the reports contained substantial theoretical or general discussions of the nature of the phenomenon of suppression. Nevertheless, for convenience of discussion, the literature reviewed will be divided into the three categories suggested above.

Interview and questionnaire studies. Some of the general findings of the interview and questionnaire studies have already been presented in Chapter 1, and will not be repeated here. The reader interested in a more detailed unclassified review and discussion of these studies is referred to Naylor, et al.,[4] or Casey and Larimore.[5] However, there are a number of conjectures concerning interview and questionnaire studies that are of sufficient interest for at least a brief mention. For example, Palmer, et al.[6] point out that data obtained from POWs need to be scrutinized very carefully before validity can be assumed, as POWs may deliberately attempt to mislead the interviewer. Palmer, et al. also point out that many such studies employed structured interviews which may have tended to lead the interviewees. Questionnaires also tend to be structured in nature. Palmer, et al. recommend the use of an unstructured interview as the most valid approach.

There is evidence from the interview and questionnaire data that familiarity with a weapon tends to reduce fear of that weapon. Or, in the case of the especially effective weapons, fear may actually increase. In other words, familiarity with weapons tends to make fears more realistic. That is, the relative fear of various weapons is likely to become more in keeping with the actual casualty-producing ability or lethality of the weapon, as familiarity with the weapon increases. However, this was not always found to be the case. In some cases, greater fear was expressed for those weapons which had most frequently been used against the individual being questioned. Fear was also found to be associated with the reputation of a weapon. For example, US forces in Africa during WWII expressed great fear of the German "88" because of its reputation for extreme accuracy.

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[4] J. C. Naylor, et al. *Proceedings of the First Symposium on the Psychological Effects of Non-Nuclear Weapons - Volume I,* University of Oklahoma Research Institute, Norman, April 29, 1964.

[5] I. J. Casey and W. E. Larimore. *Paraphysical Variables in Weapon System Analysis,* AR 66-1, Analytic Services, Inc., Falls Church, Virginia, April 1966.

[6] J. D. Palmer, et al. *Investigation of Psychological Effects of Non-Nuclear Weapons for Limited War. Volume No. II, Experimental Studies*, ATL-TR-65-39, Vol II, Directorate of Armament Development, Weapons Division (ATWR), Eglin AFB, Florida, January 1966.

Although the evidence is not substantial, there are some indications that fear of weapons is at least in part culturally determined. These data have been reviewed by Casey and Larimore.[7] They present data from Kahn[8] comparing the fears of Chinese Communist forces and North Koreans to United Nations weapons. A portion of these data is shown as Table 2-4. However, Kahn suggests that other than cultural differences may account for the differences observed in the table. He suggests, for example, that different types of weapons may have been used against the two forces, or that different proportions of combat-experienced soldiers may have served in the two armies represented. Casey and Larimore also present data on fear responses to a first air raid. It was found that Russians were less frightened than either French or Italians. Further, the Russians tended to fear large bombs the most out of five possibilities, while the French placed large bombs third. Both groups, along with Italians, placed incendiary bombs last.

Table 2-4. Most Feared United Nations Weapons

	Percent	
Weapon	Chinese	North Korean
Airplane	52	23
Strafing	16	27
Bombing	7	19
Napalm	3	13
Artillery	50	38
Machineguns	5	3
Tanks	4	1
Tank Guns	4	2
Rifles	5	1
No. of Prisoners	238	305

The inconsistency of reports concerning the effect of noise has already been mentioned in Chapter 1. That is, noise was very frequently mentioned as a reason for fear of dive bombers, while it was virtually never mentioned in connection with fear of artillery. Page, et al.,[9]

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[7] Casey and Larimore, *op. cit.*

[8] L. A. Kahn. *A Preliminary Investigation of Chinese and North Korean Soldier Reactions to UN Weapons in the Korean War*, ORO-T-14 (FEC), Johns Hopkins University, 1952.

[9] M. M. Page, et al. "Prior Art in the Psychological Effects of Weapons Systems," in J. C. Naylor, et al., *Proceedings of the First Symposium on the Psychological Effects of Non-Nuclear Weapons - Volume I*, University of Oklahoma Research Institute, Norman, April 29, 1964.

point out that the British had little fear of "shrieking" bombs. This was because of the time they could be heard before they hit. Thus, they had ample warning and could take cover, rendering the bombs largely ineffective from the antipersonnel standpoint. This is in direct contrast to the data on fear of the shrieking dive bomber cited earlier. However, the troops reporting fear of the dive bomber were in the open and therefore had little affordable protection. Hence, it can be seen that situational factors are extremely important in determining what characteristics of a weapon will produce fear.

Experimental studies. Only two series of experimental studies were located in the literature search. One of these was the series of five studies reported by Kushnick and Duffy.[10] The general procedures employed in most of this series has already been described in the Research Problem section. The first experiment was a "policy capturing" experiment designed to determine what personal as well as weapon and scenario characteristics contributed to suppression ratings. It was during this experiment that the Suppression Index was derived. The second experiment was a miss distance estimation experiment, and the third dealt with the perceived dangerousness of various live fire events. The fourth study was designed to assess the suppressive effects of impact signatures, and the fifth to determine whether physiological responses were correlated with the psychological responses to live fire events. Data collection for the impact signature study differed somewhat from the other experiments. Rounds were actually fired into the ground approximately 15 meters in front of the pit, and subjects observed the impacts through periscopes. The general conclusions drawn from this series of studies were: (1) the major factors producing suppression are the loudness of passing rounds, the proximity and number of passing rounds, and the signatures associated with rounds impacting. (2) Within the limits of the study, suppression was shown to (a) decrease in a linear fashion with increasing miss distance, (b) to increase linearly with increases in rate of fire or volume of fire, and (c) to increase in a linear fashion with increases in the perceived loudness of passing projectiles. This series of studies by Kushnick and Duffy will also be referred to hereafter as the Litton studies.

The US Army Combat Developments Experimentation Command (USACDEC) conducted a series of suppression experiments employing a wide variety of both direct and indirect fire weapons. Data from two of the more relevant experiments have been summarized in a 1976 publication.[11] The intent of these studies was to determine the proximity of fire required

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[10] Kushnick and Duffy, *op. cit.*

[11] Deputy Chief of Staff for Combat Developments, US Army Combat Developments Experimentation Command, Fort Ord, California. *USACDEC Suppression Experimentation Data Analysis Report*, April 1976.

to suppress at the .5 and .9 probability levels, and to determine the volume of fires required to obtain the same suppression levels. The suppressees were ATGM gunners who simulated the engagement of a maneuvering armored element with an antitank missile. However, the suppressees did not have the capability of engaging the base of suppressive fires. The ATGM gunners used periscopes to detect, acquire, and track the armored vehicles. In order to motivate the ATGM gunners, rewards were given based on points obtained. The defenders were given maximum points for fully exposing their periscopes in firing at the enemy. Fewer points were awarded for partially exposing the periscopes and observing without firing, and no points were awarded for keeping the periscope down in the foxhole unable to fire or to observe. Negative points were given if the periscope was hit by the suppressive fire. It was assumed that each ATGM gunner would have to remain exposed for 15 seconds to complete the engagement. That is, if a gunner withdrew his periscope during the course of the engagement, it was assumed that the missile was "lost" and that the engagement would have to be re-initiated. Suppressive fire was placed at predetermined points in a predetermined pattern and rate by a team of "attackers." The likelihood that an ATGM gunner would be suppressed at each of several miss distances was determined empirically for each weapon involved. Weapons employed in the CDEC studies which were also employed in the Litton study were the .50 caliber machinegun, the M60 machinegun, and the M16A1 rifle. It was discovered that the probability of suppression is influenced by proximity of fire in a relatively orderly or predictable manner. It was possible to model radial miss distance in meters by the following equation:

$$RMD = Ae^{B \quad P(S)}$$

Where: RMD is the miss distance in meters

P(S) is the probability of suppression

A and B are constants associated with each specific weapon type.

For the M60 machinegun, A = 89.556 and B = 5.395. Figure 2-1 presents a curve drawn through points computed for miss distances of .5, 1, 3, 6, 10, 15, and 20 meters. As can be seen, a miss distances of 6 meters results in a .5 probability of suppression, while a miss distance of less than 1 meter is required for a .9 probability of suppression. It should be noted that the data entering into each of the models was based on the results of all of the studies in which a particular weapon was involved, if the data were considered valid.

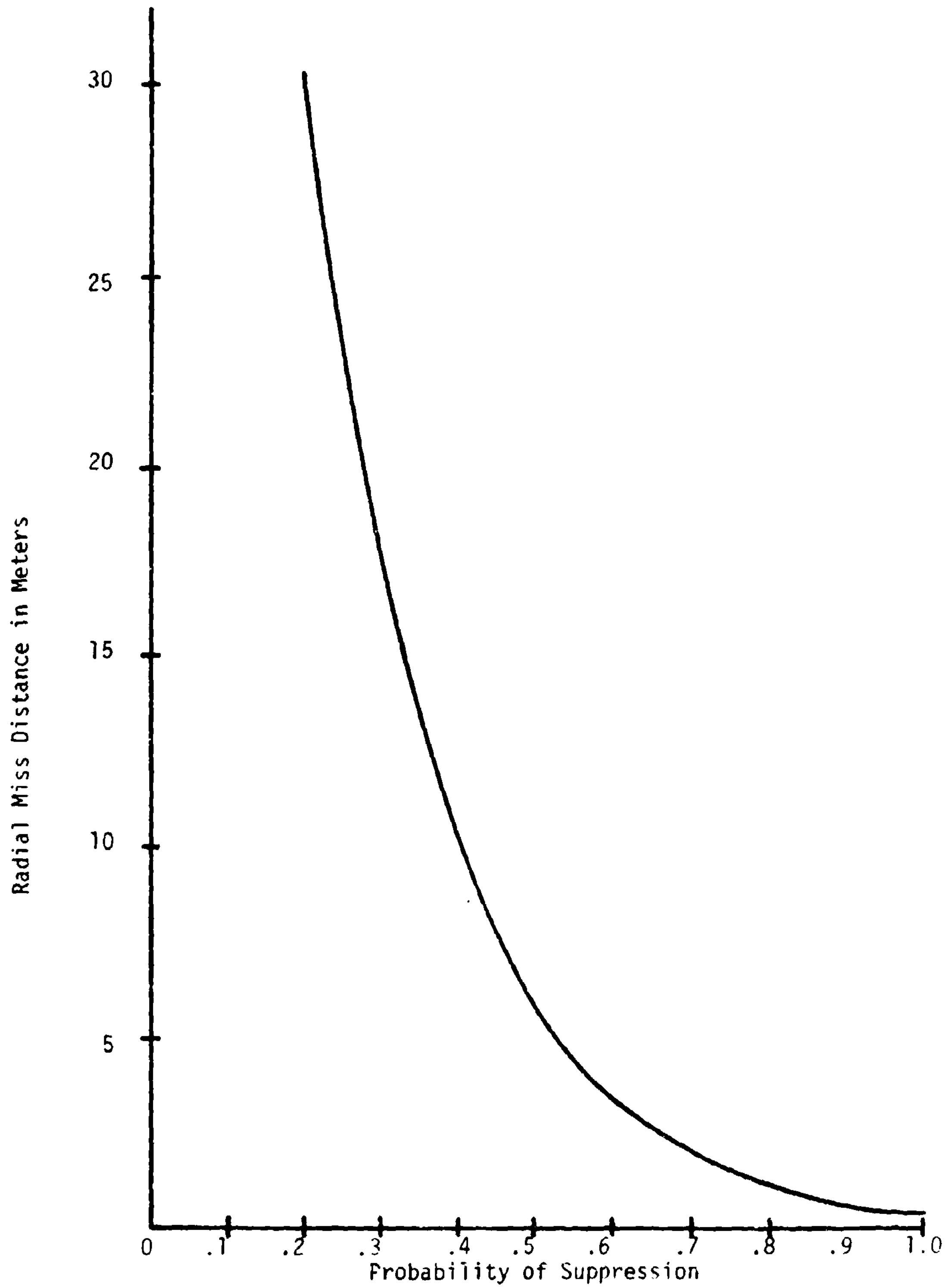

Figure 2-1. Probability of suppression as a function of radial miss distance.

Another CDEC study[12] investigated the effect of concealment on suppression. As might be expected, targets in concealed positions were less suppressed than those in visible positions. However, an interesting but unexpected result was obtained. There was a consistent tendency for the M16A1 in the semi-automatic mode to be more suppressive than in the automatic mode. In other words, rounds fired singly over a 30-second period tended to be more suppressive than rounds fired in 3-round bursts when the same total number of rounds were fired per unit of time. The authors speculate on this finding thusly:

> Since automatic fire is often believed to be more suppressive, the M16A1 on semi-automatic should have been the least suppressive of the dispersions used. The results indicate that this may not be true; in fact, the semi-automatic condition tended to be one of the most suppressive dispersions. Since 18 rounds per event were fired in each of the seven dispersions, there were six opportunities to suppress targets in the three-round burst mode, and 18 such opportunities in the semi-automatic mode during each 30 second trial. Therefore, the greater volume of fire associated with each trigger pull on the three-round burst may not compensate for the increased number of trigger pulls available with the same number of rounds in the semi-automatic mode. When the targets were visible, each trigger pull often was in direct response to sighting a target; therefore, the targets could be suppressed more times during a trial by the semi-automatic mode. The fact that the semi-automatic mode received a more suppressive ranking for visible than concealed targets supports this conjecture.

It seems to the present authors that an attempt should be made to replicate the finding just described. If the finding can be replicated, it should prove useful to both commanders and to weapons designers. The ability to fire rounds singly saves both ammunition and wear and tear on weapons, and may be equally or more effective in suppressing a hostile force.

One major difference between the CDEC studies and the Litton studies was that CDEC relied largely on objective data, while Litton

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[12] Project Team II, US Army Combat Developments Experimentation Command, and Braddock, Dunn, and McDonald Scientific Support Laboratory, Fort Ord, California. *Dispersion Against Concealed Targets (DACTS), USACDEC Experiment FC 023*, Final Report, July 1975.

relied on subjective data.[13] However, only one notable discrepancy in the conclusions drawn has been detected. Data from the CDEC study were suggestive of a logarithmic relationship between miss distance and level of suppression (see Figure 2-1). The Litton study concluded that "within the limits of the study," suppression was found to decrease in a *linear* fashion with increasing miss distance. However, the explanation for this apparent difference may be found in differences in the experimental procedures employed. In the CDEC studies described, the rounds may have actually passed closer to the observers than in the Litton study. Also, though it is not stated in the reports, the observers may have seen muzzle flashes and observed round impacts as they were employing periscopes above ground level. In the Litton studies where the Suppression Index and Perceived Dangerousness Index were derived, the observers were below ground and had no opportunity to observe muzzle flashes or impacts. Furthermore, the targets at which the weapons were fired were above ground level. From the description presented in the Litton report, the present authors estimate that the nearest miss distance was approximately 3.5 meters. Note that in Figure 2-1, that most of the curvilinearity occurs below 3.5 meters. That is, the curve is relatively straight at ranges from 3.5 meters up. If only these data were available, it would be easy to conclude that the relationship was linear. The CDEC reports present no data relative to the Litton conclusion that suppression increases with the perceived loudness of passing projectiles. Both sets of studies conclude that the proximity and number of passing rounds are associated with suppressive behavior.

Models

General considerations.

The belief that suppression does, in fact, exist, and does affect the outcome of battles, has provided the impetus for the development of mathematical models of suppression for inclusion in computer battle simulations. To the extent that the models realistically portray suppression effects, the computer simulations are improved. However, the authors of virtually all the documents describing model development admit that the models are based on assumptions and require validation. Furthermore, the assumptions vary from model to model. For example, in the FAST-VAL model,[14] it is assumed that an attacking battalion will break when they have 20% casualties and an attacking company will break when they have 30% casualties. It is further assumed that a defending

[13] CDEC also collected subjective data during the DACTS study but found it more variable than the objective data, and therefore, placed greater reliance on the objective data.

[14] S. G. Spring and S. H. Miller. *FAST-VAL: Relationships Among Casualties, Suppression, and the Performance of Company-Size Units*, RM-6268-PR, Rand Corporation, Santa Monica, California, March 1970.

battalion will break when they reach 40% casualties and a defending company will break when they reach 50% casualties. Johnson[15] points out that the theater battle model assumes that an attacker breaks contact when he suffers 15% casualties, while a defender breaks contact after suffering 30% casualties. Obviously, both sets of these assumptions cannot be correct. Also, the use of a fixed percentage does not seem to be realistic. An Operations Research Office report[16] describes the analysis of a number of battles in which US forces were both in attack and defensive postures. The breakpoints proved to be quite variable from battle to battle. All of the conditions leading to this variation could not be ascertained. However, such factors as the total length of the battle and the availability of reinforcements appear to be factors. The authors also suggest that the quality of leadership and experience of the personnel *may* have been factors. The influence of factors such as these must be determined before the models can be refined.

As discussed in Chapter 1, there is also disagreement on the duration of suppression. The Ad Hoc Group[17] noted that most models assume constant durations of 10 to 60 seconds. Again, the employment of a constant value seems unrealistic. Concealment, for example, was shown by CDEC[18] to be related to suppression time, with concealed targets being less suppressed than targets in the open. Other factors are undoubtedly involved. However, refinement of this aspect of the models must wait the accumulation of data delineating the contribution of the various factors. Further experimental research, and possibly further analysis of past battles, are required.

Work conducted by the Systems Research Center at the University of Oklahoma suggests the difficulties that are likely to be encountered in attempts to refine battle simulations to fully account for psychological

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[15] E. C. Johnson, Jr. "The Effect of Suppression on the Casualty Exchange Ratio," Masters Thesis, Naval Postgraduate School, Monterey, California, March 1973.

[16] D. K. Clark. *Casualties as a Measure of the Loss of Combat Effectiveness of an Infantry Battalion,* TM-ORO-T-289, Operations Research Office, Johns Hopkins University, August 1954.

[17] US Department of the Army, Office of the Deputy Chief of Staff for Research, Development, and Acquisition, Washington, D.C. *Report of the Army Scientific Advisory Panel Ad Hoc Group on Fire Suppression,* ODCSRDA Form 11, 7 July 1975.

[18] Project Team II, *op. cit.*

variables. For example, Terry, et al.,[19] formulated a psychological index of weapons effectiveness. They described the psychological index as "a system of measurements, which will permit quantitative description of the psychological effects of weapons." The index is referred to as the SRC Psychological Index, where S stands for signature value, R for reputation value, and C for context value. The signature variables are sound spectrum, sound intensity, light spectrum, light intensity, injury capability, and flame capability. Despite the multiplicity of factors considered, Terry, et al., did not mention impact signatures, which the Litton studies showed did affect psychological ratings. The reputation variables are familiarity, experience, predictability, forewarning, accuracy, lethality, countermeasures, and protection. Under context are listed 16 force variables, 10 unity variables, and 4 leadership variables. Force refers to those factors relevant to the degree of military might which can be employed by an enemy. Unity variables are those which are relevant to the cohesiveness of an enemy unit, and include such things as propaganda effects, the reputation of the unit, and their personal motives. The leadership variables pertain to leadership quality. As can be seen, assuming that all of the variables listed by Terry and co-workers are relevant to the psychological effects of a weapon, prediction of the effects is exceedingly complex. Terry, et al., were not dealing specifically with suppression, but with psychological effects in general. However, it is certainly conceivable that all of the variables mentioned might be factors in the suppressive capability of a weapons system.

Page, et al.,[20] delve into the responses to weapons systems. They state that weapons-specific variables (e.g., weapon efficiency, visual aspects, noise, duration, etc.) and situational variables (available protection, proximity, leadership, mobility, etc.) form the stimulus complex which impinges on the individual human. These variables interact with personal characteristics, which they refer to as organismic variables. Organismic variables are defined as experience, expectations, personal involvement, physiological condition, and predisposition. The result is a set of responses. These responses are divided by Page, et al., into immediate behavioral changes and long-range behavioral changes. Immediate changes include such things as panic, immobility, fatigue, poor performance, and flight or escape behavior. Long-range changes might be lowered morale, irrational thinking, regression, or even neurotic and psychotic disorders. This concept by Page, et al., of course, assumes a behavioral response which is desirable from the standpoint of the weapon user. Otherwise, the weapon would have no relevant psychological effect.

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[19] R. A. Terry, et al. *Development of Weapons Design Criteria Based on the SRC Psychological Index: An Investigation of Signature, Reputation and Context Effects*, Technical Report AFATL-TR-87-185, Air Force Armament Laboratory, Air Force Systems Command, Eglin AFB, Florida, October 1967.

[20] Page, et al., *op. cit.*

The work of Page, et al., and Terry, et al., does illustrate the complexity of the problem of predicting the psychological effects of weapons. However, it should be noted that the problem posed for this present research is less complex. Kushnick and Duffy noted that their respondents were reacting primarily to the sounds of the passing projectiles. What Terry, et al. refer to as context variables probably played an insignificant role. The situation or scenario given to each respondent was only briefly described, and the responses were limited to the seven choices presented. Organismic variables undoubtedly did come into play. That is, each individual reacted in his own individual manner. No attempt, however, was made to measure these variables other than to obtain a very limited amount of biographical information. Therefore, our present concern is almost solely with the signature variables.

Huggins[21] presents an explanation of how the suppression pheonomenon works. Once a fire fight is initiated, all combatants tend to take cover. The next reaction is to assume a firing position and attempt to locate targets on which to deliver aimed fire. If no targets can be detected, a normal reaction is to deliver area fire at the assumed target location. Thusly, the fire fight tends to restrict the movement of the individual combatants. If one side is able to increase its fire, the other side is forced to take greater cover, is less able to detect targets, and therefore, it less able to return fire. In this manner, one side tends to assume fire superiority and the other side is said to be suppressed. The more one side is suppressed, the less they can deliver fire, and therefore the degree of suppression increases as the opposing side is able to deliver even greater volumes of fire. In theory at least, one side could become totally suppressed, allowing the other side to maneuver freely against them. However, in practice, there is a limit to the amount of fire any one side can deliver. Weapon wear and ammunition supplies dictate some restraint. Also, unless some of the fires are lethal, the suppression will only result in a delay and not a victory. In other words, the purpose of suppression appears to be that of gaining the advantage in mobility and the ability to observe, but must be followed by lethal fire in order to achieve a victory. Tepas[22] also discusses the purpose of suppression. He feels that it is a harassment designed to fatigue the enemy by interference with work-rest cycle and biorhythms. Ideally, the harassment weapons should

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[21] A. L. Huggins, Jr. "A Simplified Model for the Suppressive Effects of Small Arms Fire," Masters Thesis, Naval Postgraduate School, Monterey, California, September 1971.

[22] D. I. Tepas. "Some Relationships Between Behavioral and Physiological Measures During a 48-Hour Period of Harassment; A Laboratory Approach to Psychological Warfare Hardware Development Problems," in J. C. Naylor, et al., *Proceedings of the First Symposium on the Psychological Effects of Non-Nuclear Weapons - Volume I*, University of Oklahoma Research Institute, Norman, April 29, 1964.

fatigue the enemy to the extent that he eventually falls into a deep sleep, and is therefore completely suppressed. That this may actually happen is attested to by an incident reported by Page, et al.[23] They state:

> An example of hyperreaction is given in a report from a company pinned down while on the offensive in Korea. While undergoing intense fire and infighting for several hours, officers reported at mid-day that their most difficult problem was keeping the men awake and firing their weapons. This feeling of fatigue and extreme sleepiness, where it was not physically justified, was an avoidance hyperreaction to an especially intense weapons effect.

Tiedemann and Young[24] present an interesting notion on suppression which is essentially weapons-independent. They suggest that successive impacts of rounds coming closer and closer to an individual are likely to be more suppressive than rounds going in the other direction, or rounds randomly placed, or all hitting in the same spot. Whether this is true or not, it has a logical appeal. It might even be assumed that impacts at successively greater distances from an individual would hardly have any suppression effects at all.

Burt, et al.,[25] report on an interesting finding which certainly seems to be related to suppression. In an analysis of several battles, it was found that as artillery strength increased, the relative proportion of casualties by artillery decreased. The same apparently contradictory relationship was also found for small arms. This may be explained in part by assuming that increases in one kind of fire power caused personnel to take cover from that kind of fire power. However, it is difficult to imagine that personnel taking cover from artillery fire would not also be protected from small arms fire. Nevertheless, Burt, et al., suggest this possibility. They state:

> It seems reasonable to expect that when the enemy artillery fire power is great, stronger friendly bunkers are constructed and unnecessary friendly movement is curtailed. In addition, increased

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[23]Page, et al.,

[24]A. F. Tiedemann, Jr. and R. B. Young. *Index of Promixity: A Technique for Scoring Suppressive Fire*, ER 6419, AAI Corporation, Baltimore Maryland, October 1970.

[25]J. A. Burt, et al. *Distribution of Combat Casualties by Causative Agents*, Technical Memorandum RAC-T-445, Research Analysis Corporation, McLean, Virginia, March 1965.

enemy artillery fire power may have been employed to allow the enemy infantry to come into direct contact with the friendly forces where they would make use of their small-arms weapons. This would reduce the percentage of casualties caused by artillery but increase the percentage caused by enemy small arms.

The authors also point out that their data are based on the *relative* or proportionate number of casualties. That is, increases in artillery fire power may also cause increases in the absolute number of casualties, but may still comprise a relatively smaller proportion of the total casualties.

In closing this general discussion section, reference is made to the work Winter and Clovis,[26] who followed up on the earlier work by Kushnick and Duffy. These authors were unable to find any quantitative data on suppressive effects. Due to this lack, they analyzed over 100 anecdotal reports of combat situations from WWII, Korea, and Vietnam. The level of suppression was determined judgmentally by comparing the behaviors described in the various reports. Unfortunately, quantitative data on a number of crucial variables such as volumes of fire were not available. Therefore, considerable subjectivity was involved in the analysis. They searched specifically for data on signatures, including visual, auditory, olfactory, seismic, and thermal signatures. They divided signatures into platform signatures, initiation signatures, trajectory signatures, and terminal signatures. Suppressive effects were noted on the ability to fire, move, observe, and communicate. The authors concluded that the "expected fraction of casualties," or lethality expectations associated with the weapon, takes into account all of the multiplicity of characteristics considered by others. Therefore, the model they developed had one parameter for weapons performance and one for "subjective aspects associated with human beings. This conclusion, that lethality is the only weapon parameter involved in suppression, certainly has appeal. If true, weapon signatures as such play no part in suppression except as recognition aids. That is, if the signature identifies the weapon as being of high lethality, it will lead to greater suppressive behavior. However, the present authors feel that this approach is too simplistic, as lethality is only one of a number of relevant factors. Other studies have consistently shown that fear of a weapon and its casualty-producing ability are not perfectly related, even among highly experienced battle veterans. But, until the contribution of other factors, if any, can be determined, the use of a single factor such as lethality may be the best approach. With regards to the human factors involved, these authors

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[26] R. P. Winter and E. R. Clovis. *Relationship of Supporting Weapon Systems Performance Characteristics to Suppression of Individuals and Small Units,* TR 73/002, Defense Sciences Laboratories, Mellonics Systems Development Division, Litton Systems, Inc., Sunnyvale, California, January 1973.

make an interesting recommendation. They recommend that no further experimentation on suppression be done. They feel that the suppression phenomenon is too complex and that the state-of-the-art in the behavioral sciences is not sufficiently advanced to yield any results of practical value.

Invariant models.

No attempt was made to locate information on all of the computer battle simulations devised by the military services. Many of the models originally examined did not play suppression at all, and will not be discussed here. There are undoubtedly others which do play suppression on which no information was located during the literature search. A complete reporting and description of the models reviewed did not seem necessary, as they had much in common. Therefore, the models which will be briefly discussed below should be considered as only a sampling of the total universe.

The models developed to date are largely invariant. That is, there is no "human factor" built into the assumptions. A given fire event in a given circumstance always results in the same degree and duration of suppression. This does not mean that the authors do not realize that a human factor exists. Most admit that it does, but that they lack the means for quantifying it. So, in essence, the models assume an "average" behavioral response on the part of the suppressed force. However, as discussed earlier, there is a notable lack of agreement on such things as the duration of suppression and the breakpoints (in terms of percent casualties) at which a force will abandon its mission.

A brief review of some of the major features or characteristics of some of these models is presented below.

a. Kushnick and Duffy used kinetic energy of the projectiles as a first approximation of the suppressive effects of a weapon. (See pages 2-1 through 2-3 of this chapter.) As mentioned earlier, they found that a curvilinear relationship existed between kinetic energy and perceived dangerousness. This particular finding will be discussed more fully in Chapter 3. The authors do acknowledge that factors such as the nature of the mission, availability of cover, combat experience, training, time in combat, and basic psychological makeup of the individual do mediate the suppressive effects of weapons. However, they make no attempt to deal with these variables in studying the relationship between kinetic energy and individual variations in perceived dangerousness. They present data dealing with only the average of the responses.

b. Aiken, et al.,[27] employing the data obtained by Kushnick and Duffy, attempted to scale weapons effects between 0 and 100% suppres-

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[27] A. C. Aiken, W. L. Phillips, and D. V. Strimling. "Individual Suppression as Induced by Direct Fire Solid Projectile Weapons: Its Effect and Duration," (U), ARI paper, 30 April 1975.

sion. To do this, they assumed that no fires would result in no suppression, and that a specific level and proximity of fires from a given weapon would result in 100% suppression. Employing the kinetic energy of projectiles, they were able to derive constants for their equations which relate all fires to this scale. However, they were quick to point out that once suppression reached 100%, that no additional fires could result in a greater degree of suppression. In other words, once the critical level of fires was achieved and suppression was complete, increasing fires would have no further suppressive effect and would therefore be wasteful.

c. Kinney,[28] though concerned with the development of a model for predicting suppression effects from fragmenting explosive warheads, assumes that miss distance is the only criterion for determining suppressive behavior. However, since various miss distances for various weapons represent different kill probabilities, he assumes that P_k is actually the physical variable which induces the psychological response of suppression.

d. Like Kinney, Tiedemann and Young[29] assume that the proximity of impacting rounds is the determinant of suppressive behavior, and they develop an index based on impact distances. Moreover, they state that successively closer impacts result in greater suppression than impacts at successively greater distances. However, they make no attempt to deal with individual differences or the effects of specific signatures of weapons systems.

e. Burt, et al.[30] attempted to relate such things as enemy personnel strength, artillery fire power, small arms fire power, ammunition supply, and weather to the incidence of casualties caused by either artillery, small arms, bombs, etc. Other qualitative variables were considered, such as terrain, vegetation, and morale, but were discarded because data were simply not reliable or were incomplete. Ammunition supply was discarded because data were not available in many instances. Burt and his co-workers analyzed data for five WWII battles and 16 Korean battles. They obtained a multiple correlation of .85 for predicting casualties from artillery, and a correlation of .77 for predicting casualties from small arms. However, conflicting results were obtained in the validation attempt. The equations failed to predict casualties in another battle from WWII, but were quite good in predicting casualties from another battle in the Korean War. In developing the equations, small arms were considered as a single category and casualties produced by different kinds of small arms were all considered to be the same. While the correlations are quite substantial, they do fail to

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[28] Kinney, *op. cit.*

[29] Tiedemann and Young, *op. cit.*

[30] Burt, et al., *op. cit.*

account for a considerable portion of the variance. In other words, measures of weapons lethality alone are not necessarily good predictors of casualties. The observed differences in casualty rates between battles *may* have been due to differences in enemy firing accuracy (i.e., proximity of impacting rounds). It *may* also have been due to differences in the protection available for or experience levels of the friendly forces. Both of these latter factors would also be *expected* to be related to suppressive behavior. If these factors were also at play, measures of lethality (including proximity measures) alone would be expected to predict neither casualties nor the degree of suppression of friendly forces. Further data are needed to determine the contribution of the various factors.

The models described indicate something of the range and types of models which have been developed. There are many others. The Ad Hoc Group, for example, presents a table listing the major characteristics of six other models of varying sophistication, all of which appear to be of the invariant type.

Examples of human factors models.

The models which include a human factor also make many of the same kinds of assumptions as the invariant models. That is, the weapons effects portion of the models is typically calculated in the same manner as in the invariant models. However, the final results are modified by introducing a human factor.

a. The SRC Psychological Index developed at the University of Oklahoma[31] represents an attempt to model all of the non-weapons specific factors in weapons effects. Strictly speaking, the Index is not a model since a means for numerical computation of index values was not provided. Rather, it simply provides a framework for a model which is in need of validation. Since this psychological index was discussed at some length earlier, no further details will be presented here.

b. Winter and Clovis[32] developed a model based on the expected fraction of casualties and a human factors coefficient. The expected fraction of casualties was based on the number of rounds fired, the lethal area per round, the area over which target elements are dispersed, and the circular probable error. They state that the human factors coefficient (rho):

> ...represents the aggregate of effects of human factors and other intangibles relating to morale, leadership, tactical situation, fear/danger ratio, and so forth; it has a nominal

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[31] Terry, *op. cit.*

[32] Winter and Clovis, *op. cit.*

value of 1. Use of values greater than 1 implies conditions resulting in higher suppressive levels than the threat would typically elicit; inexperienced troops, for example. If conditions are such that lower than typical suppression levels will occur, as might be in the case of a crucial defense by veteran troops, then a value of rho less than 1 is appropriate.

Unfortunately, the value of the human factors coefficient must be determined subjectively.

c. FAST-VAL II (Forward Air-Strike Evaluation)[33] is a model developed by the Air Force "...to define in analytic terms those relationships that describe the performance of a well-led and well-disciplined infantry company during a fire fight." Weapons effects are modeled in FAST-VAL by computing casualties based on the numbers of personnel in a given area and the levels of fire directed against them. The vulnerability of personnel is determined by the posture of the personnel. For example, personnel may be assumed to be in the prone position, standing in foxholes, crouching in foxholes, or in log bunkers. When the casualty rate exceeds a given value, personnel revert to a less vulnerable posture. Less vulnerable postures represent suppressed states. When the casualty rate for a given period of time is less than some fixed number, personnel revert to a more vulnerable posture. The human factor is built into the model by the user in two ways. One, the user determines the casualty rate at which a force will seek their second, more suppressed posture. Two, the user selects a fractional efficiency for each of the postures available in the model. In this way the user determines both when suppression will occur and what its effect will be on the performance of the suppressed individuals. At least according to the description provided by Spring and Miller,[34] percent casualties is the only factor entering into suppression. This seems a bit unrealistic in terms of what other investigators have found about behavior under fire.

Although they made no attempt to model the human factor, other writers have indicated that human factors variables ought to be included in models. For example, Reddoch,[35] though presenting a model of the invariant type, suggests that human considerations may alter the relationship between lethality and suppressed behavior. He suggests that when a weapon becomes too lethal, it may have no suppressive effect at all. Reddoch invokes the concept of "negative suppression" for this

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[33] Spring and Miller, *op. cit.*

[34] *Ibid.*

[35] R. Reddoch. "Lanchester Combat Models With Suppressive Fire and/or Unit Disintegration," Masters Thesis, Naval Postgraduate School, Monterey, California, March 1973.

contingency. If a weapon is so lethal that the target individuals believe that seeking protection will be useless, then they will make an all-out effort to destroy the weapon before it hits them. He cites flamethrower tanks as such weapons during WWII. Normally, personnel in bunkers would be suppressed by fire from conventional tank weapons. However, the flamethrowers represented a threat of near-certain destruction regardless of the bunker, so that virtually any risk appeared justified to destroy the tanks. The same situation held when gun boats in Vietnam had their 40mm weapons replaced by the 105mm howitzer. The 40mm's were replaced because they had proven ineffective against enemy bunkers. The 105mm was able to penetrate and destroy the bunkers. The result of the change was increased friendly casualties. Again, the enemy felt that since the bunkers offered virtually no protection, they were not suppressed, continued to fire, and inflicted heavier casualties on friendly forces.

Casey and Larimore[36] concluded that both the culture in which personnel were raised and their individual personalities affected their reactions to various kinds of weapons. They suggested the concept of a "modal personality" to account for these kinds of differences. Casey and Larimore also feel that the situation is an important determinant of behavior under fire. The situation is made up of the physical objects and conditions (cover, mobility, etc.). However, the authors suggest that it is more the combatant's perception of the situation than the actual situation which influences his behavior.

To recapitulate, virtually all of the model makers, even those who developed invariant models, believe that a human factor exists. However, attempts to include human variation in models have been rudimentary at best. It is obvious that a great deal more work needs to be done to define the situational, cultural, and individual variables which influence behavior under fire.

[36] Casey and Larimore, *op. cit.*

Chapter 3

ANALYSIS

The original intent of this effort was to determine whether any aspect of the acoustic signatures of the weapons employed by Kushnick and Duffy[1] could aid in predicting the Suppression Index and Perceived Dangerousness Index they derived. Based on their own observations, plus reports from their subjects, they felt that the acoustic signatures of the passing projectiles were virtually the sole determinants of the ratings made. They stated:

> It was the opinion of both the subjects and the DSL analysts that the basic stimulus that allowed the subjects to perceive and note the dangerousness of the events in the field experiment was produced by the projectile signatures and not by the characteristics of the muzzle blasts of the weapons themselves.... The obvious overt characteristic producing the perception of danger is the loudness of the signature of passing projectiles....

The purpose of the present exercise was to obtain some notion on what aspect or aspects of the signatures affected suppression other than perceived loudness. Such information, if later proven valid, might be of considerable use to both commanders in the field and to weapons designers. It was, of course, realized that any results would be tentative, due to the small number of weapons involved in the study. However, the results were not intended to provide the ultimate solution. Rather, they were only intended to suggest hypotheses to provide direction to further experimental work on suppression.

Unfortunately, the data desired could not be located. Much of the relevant data located were not in the open literature, but rather were obtained from the files of various agencies through personal contacts with individuals in those agencies. All of the individuals contacted expressed serious doubts that the type of data requested existed at all. Two reasons were given. First, the measurement of weapons signatures was made almost entirely in the interests of safety. The efforts were directed towards determining whether weapon noises met design specifications and/or exceeded the standards set forth in MIL-STD 1474 (MI).[2]

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[1] S. A. Kushnick and J. O. Duffy. *The Identification of Objective Relationships Between Small Arms Fire Characteristics and Effectiveness of Suppressive Fire*, TR 72/002, Final Report, Mellonics Systems Development, Litton Industries, Sunnyvale, California, 3 April 1972.

[2] Department of Defense. "Noise Limits for Army Materiel," MIL STD-1474 (MI), Washington, D.C., March 1973.

Therefore, measurements were typically taken at the firer's ear, and at distances up to two meters to the left and right of the muzzle. These latter measurements were to determine whether or not the weapon posed a hearing hazard to adjacent individuals. In the case of weapons fired from a vehicle, measurements were taken at the various crew positions. It was pointed out, that at least with small arms, there was little concern about the safety of individuals 150 meters down range, as friendly troops were unlikely to be in such positions. Only two studies were located where down range measurements were obtained. Second, the instrumentation required to accurately measure weapons signatures is extremely sophisticated and is believed to be available only to research and development agencies. Therefore, personal contacts felt that if any such data were available, it would have been obtained by or known to personnel at the various agencies contacted. Since none of the personal contacts recalled having seen any such data, they felt that it was unlikely to have ever been obtained.

The data which were obtained dealt largely with peak sound pressure levels and with the durations of the A and B waves. Some analyses of the sound spectra were available, but were judged to be of little use. First of all, most of the measurements were made near the weapon and contained blast as well as projectile noises. Secondly, there appeared to be no clear-cut differences in the spectra that were easily quantifiable. For example, Garinther and Kryter[3] provide data showing that the M16 spectrum has a relatively flat amplitude between 0 and 15,000 hertz, except for short bandwidth dips around 7000 and 9000 hertz. The spectral analysis of the M14 is similar, except that the big dip in amplitude centers at about 12,000 hertz with a smaller one at 3000 hertz. Several other weapons showed no such missing bands in the lower part of the audible spectrum. With the small number of weapons for which suppression indices were available, attempts to use these types of data did not appear warranted.

Although most of the measurements of acoustic signatures were obtained near the weapon to evaluate hearing hazards, some data were obtained down range. These data were not obtained to evaluate the suppressive qualities of the weapons. Rather, they were obtained to determine the ranges at which passing projectiles could be detected and to ascertain whether the actual location of the weapon itself could be determined. These data, reported by Garinther and Moreland,[4] indicate

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[3] G. R. Garinther and K. D. Kryter. *Auditory and Acoustical Evaluation of Several Shoulder Rifles*, Technical Memorandum 1-65, US Army Human Engineering Laboratories, Aberdeen Proving Ground, Maryland, January 1965.

[4] G. R. Garinther and J. B. Moreland. *Acoustical Considerations for a Silent Weapon System: A Feasibility Study*, US Army Human Engineering Laboratories, Aberdeen Proving Ground, Maryland, October 1966.

the complexity of the problem addressed by this effort by enumerating the wide variety of factors which affect down range acoustic signatures of projectiles.

Meteorological conditions, especially humidity and wind (both direction and velocity), were found to have significant effects on audibility. Similarly, the density of vegetation was found to influence the signature. The mental state of the listener was also found to be important. For example, subjects whose sole task was to await and attend to projectile noises detected at greater ranges than subjects who were also attending to another task. However, division of attention should not have been a factor in the Kushnick and Duffy study. All subjects were told to attend solely to the weapon signatures. Variations in meteorological conditions might have had an effect, but these data were not reported by Kushnick and Duffy. Photographs of the test site show that vegetation in the area was negligible. Therefore, variations in vegetation from subject to subject or time to time could not have been a factor. However, had there been vegetation, the acoustic signatures might well have been quite different. Garinther and Moreland also present data comparing the spectrum obtained at 80 meters with that obtained 2 meters from a weapon. It is obvious from the graphs presented that considerable wave form distortion occurred during the propagation over an open field. Exactly how the spectrum is influenced with increasing range is not specified. However, Garinther and Moreland do indicate that the differences are noticeable to the human ear.

Only one study was located which measured peak sound pressure levels down range. Garinther and Mastaglio[5] placed microphones down range at 115 yards, 315 yards, and 515 yards. Rounds were fired 10 feet over the microphones. They found that both peak sound pressure levels and durations were essentially constant from 115 yards through 515 yards. That is, peak SPLs varied by less than one decibel (dB). The peak for the M14 rifle was approximately 20 dB less than that measured near the muzzle. However, measurements at the muzzle, averaging 167.5 dB, were obtained from four feet from the left and right of the muzzle. The down range measurements, ranging from 147.1 to 147.8 dB, were obtained from the greater distance of 10 feet. A comparable decrement of 20 dB was also obtained for the AR 15, a .223 caliber weapon. Since the down range measurements were taken at a greater distance from the flight path, a lesser SPL would be expected. Unfortunately, Garinther and Mastaglio made no measurements 10 feet from the muzzle itself. Nevertheless, the loss in peak SPL down range appears not to be great. However, the duration of the impulse was shorter down range. For example, measurements of the duration four feet from the muzzle of the M14 varied from 3.0 to 3.4 milliseconds. The down range measurements varied from 1.0 to 1.1 milliseconds.

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[5] G. R. Garinther and G. W. Mastaglio. *Measurement of Peak Sound-Pressure Levels Developed by AR15 and M14 Rifle Bullets in Flight*, US Army Human Engineering Laboratories, Aberdeen Proving Ground, Maryland, January 1963.

Garinther and Moreland present some other data which appear to be highly relevant. In their effort to determine the characteristics of projectiles which minimize acoustic signatures, they found that projectiles which tend to yaw produce louder noises. One type of projectile they tested could be heard from only two or three meters at short ranges away from the muzzle. However, yaw began to increase down range from the muzzle, and at 150 meters down range it could be detected at much greater distances from the flight path. The authors attributed this to the shape of the projectile. Therefore, any tendency to yaw may be expected to alter the signature of a projectile rather markedly as it proceeds down range.

From the preceding discussion, it can be seen that a whole host of factors affect the down range signatures of passing projectiles. In other words, one must know what the meteorological conditions are, what type of terrain is being fired over, and what type (shape) of projectiles are fired before the acoustic signatures at any point down range can be known. Many of these factors were not reported by Kushnick and Duffy. However, even if they were, the data required to predict the exact signatures at 150 meters are simply not available. Therefore, it is impossible to know at the present time exactly what was heard Kushnick and Duffy's subjects. Had their subjects been slightly closer or slightly farther away, or had meteorological conditions been different, the suppression indices obtained might have been different. As a result, it can only be assumed that the indices obtained are representative, and would remain relatively stable across a variety of ranges and meteorological conditions.

Despite the reservations implied in the previous discussion, and the general paucity of data on weapons signatures, the data reported by Kushnick and Duffy are worthy of further consideration. First of all, the question of the reliability of the indices should be examined. It can be noted in Table 2-2 that the variability of the ratings for each of the weapons was quite large in comparison to the mean. Generally, this indicates that the distributions were skewed, but it also indicates that there were wide differences in individual expectations of behaviors under fire. However, the means may still be quite stable, as each mean is based on a large number of observations.

Based on Kushnick and Duffy's work, both Winter and Clovis,[6] and Aiken, et al.,[7] employ kinetic energy as the nearest physical correlate

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[6]R. P. Winter and E. R. Clovis. *Relationship of Supporting Weapon Systems Performance Characteristics to Suppression of Individuals and Small Units*, TR 73/002, Defense Sciences Laboratories, Mellonics Systems Development Division, Litton Systems, Inc., Sunnyvale, California, January 1973.

[7]A. C. Aiken, W. L. Phillips, and D. V. Strimling. "Individual Suppression as Induced by Direct Fire Solid Projectile Weapons: Its Effect and Duration," (U), ARI paper, 30 April 1975.

of subjective loudness in attempts to develop models of suppression. It is interesting to note that Garinther and Moreland were also concerned with subjective loudness. They considered peak SPL, energy, impulse, and phons (ASA procedure) as correlates of loudness for subsonic projectiles. They concluded that impulse was the best measure, and that impulse was proportional to the cross-sectional area of the projectile. For supersonic projectiles they state:

> The primary factor which determines a supersonic projectile's loudness is the shock strength it generates. In turn, the strength of the shock wave depends primarily on the projectile's maximum diameter.

However, they do not provide a means for computing the subjective loudness of a subsonic projectile to place its value on the same scale as a supersonic projectile. Both Winter and Clovis, and Aiken, et al., assumed that Kinetic Energy (KE) was the correlate of loudness rather than diameter. Diameter is not necessarily proportional to KE as both total mass and velocity are involved. Nevertheless, it should be noted that the M60 projectile, with a KE x 10^{-8} of 3.63 received a perceived dangerousness rating of 41 (see Table 3-1). The AK 47 projectile, while having a KE x 10^{-8} of only 2.20, received a perceived dangerousness rating of 39. Both projectiles have a diameter of 7.62mm. The closeness of the psychological values provides some support to the notion that diameter is a primary factor in subjective loudness.

Table 3-1. Relationship Between Projectile Diameter, KE, and Perceived Dangerousness

Weapon	Projectile Diameter	KE x 10^{-8}	Perceived Dangerousness
Caliber .50	12.7mm	27.79	47
M60	7.62mm	3.63	41
AK 47	7.62mm	2.20	39
M16	5.56mm	1.33	37

Garinther and Moreland do not state that diameter and subjective loudness are linearly related. Certainly, a linear relationship between diameter and perceived dangerousness was not established by Kushnick and Duffy's work. A graph portraying the relationship between weapon and perceived dangerousness is presented in Figure 3-1. It is obvious that the .45 caliber weapon, which had the second largest diameter of those involved, was perceived as being among the least dangerous of the six weapons studied. The .45 caliber weapon was, of course, the only subsonic projectile among the six. Therefore, as can be seen from Figure

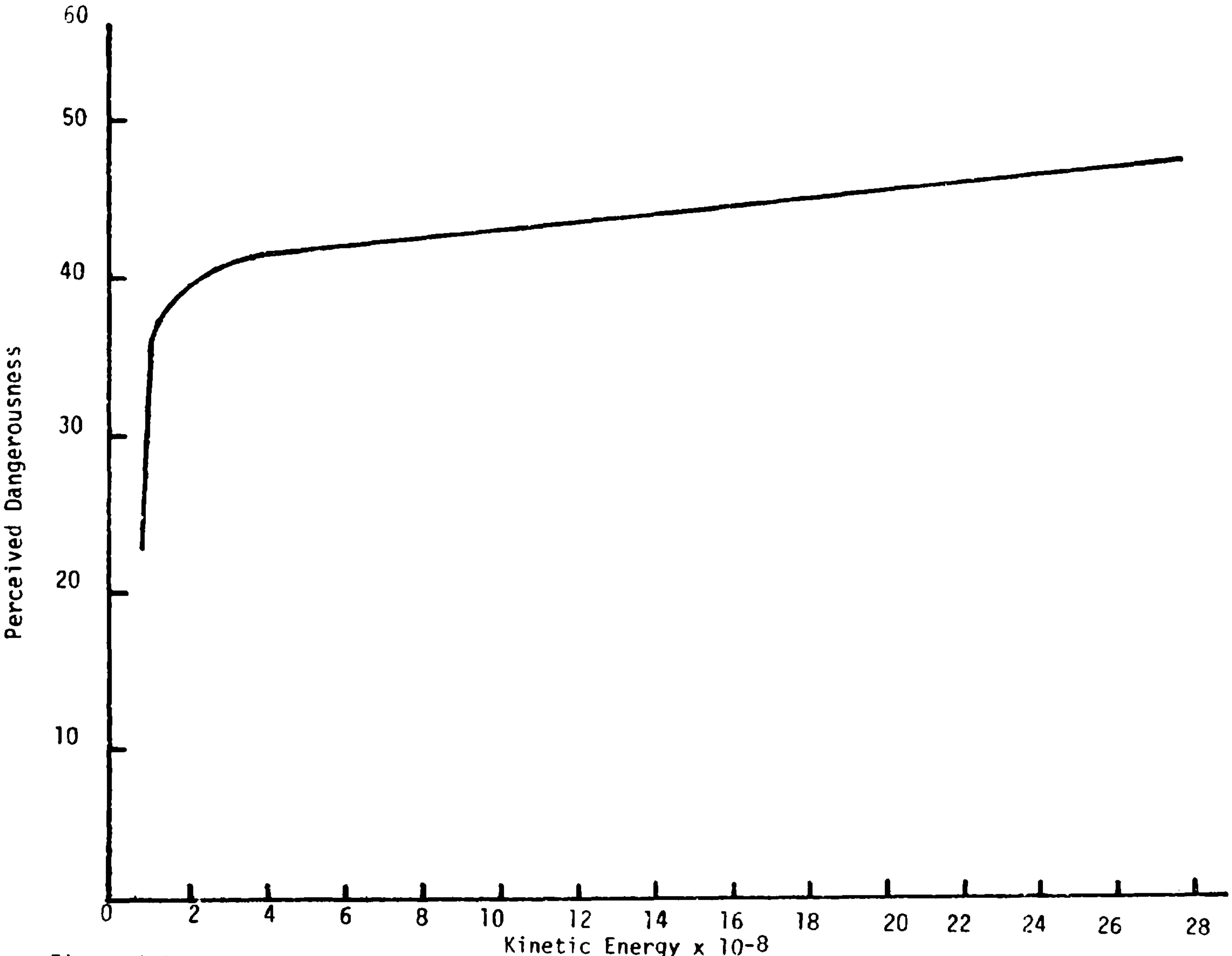

Figure 3-1. Perceived dangerousness as a function of kinetic energy (adapted from Kushnick and Duffy).

3-1, its position among the other weapons would not be a function of its diameter.

Although the signature data desired were not available, some further examination and analysis of the data presented by Kushnick and Duffy seemed warranted in light of other works. As was noted in Chapter 2, there were some apparent discrepancies between the conclusions drawn by the CDEC investigators[8] and the Litton investigators.[9] For example, the CDEC team found a logarithmic relationship between miss distance and suppressive behavior. The Litton team concluded, that within the limitations of their study, the relationship was linear. As pointed out in the previous discussion, this quite possibly could have been due to differences in the actual miss distances employed. However, a nonlinear relationship might have been postulated on a priori grounds. It is well known that the physical energy of an auditory stimulus decreases with the square of the distance from the receptor. Hence, on a priori grounds, one might expect a second degree equation to provide the best fit to miss distance data (see Figure 2-1, Chapter 2, page 2-10). Of course, exponential equations and second degree equations can take very similar forms. In either case, most of the curvilinearity tends to occur near the origin, or in this case, it would be expected to occur at the lesser miss distances. In the Litton studies, it is estimated that the observers were a minimum of approximately 3.5 meters from the passing rounds. This would place the minimum miss distance from the observer's ears on the more linear portion of the curve.

In the Litton studies, Kushnick and Duffy show a graph portraying the relationship between kinetic energy and the psychological variable of perceived dangerousness. This graph was shown earlier as Figure 3-1. The curvilinearity of the relationship is obvious from the graph. Kushnick and Duffy reported no attempt to fit a curve to the observed data. The shape of the curve, however, might have been expected, again on a priori grounds. It has been known since the days of Weber and Fechner that the relationship between physical and psychological scales tended to be exponential in nature. If kinetic energy is indeed directly proportional to the physical energy of the auditory stimulus, then an exponential relationship between kinetic energy and perceived loudness could be postulated. In any event, an attempt to fit an exponential curve to the data appeared to be worthwhile. Kushnick and Duffy do not report the perceived dangerousness ratings, so the values

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[8] Project Team II, US Army Combat Developments Experimentation Command, and Braddock, Dunn, and McDonald Scientific Support Laboratory, Fort Ord, California. *Dispersion Against Concealed Targets (DACTS), USACDEC Experiment FC 023*, Final Report, July 1975.

[9] Kushnick and Duffy, *op. cit.*

employed were read from the graph. The equation derived for predicting perceived dangerousness from KE x 10^{-8} is:

$$PD = \frac{\ln[(x-a)/b]}{c}$$

where $x = KE \times 10^{-8}$

$a = .927182$
$b = 4.28471 \times 10^{-7}$
$c = .382161$

A computed perceived dangerousness value was obtained for each of the six weapons employing the above equation. Table 3-2 lists the weapons, the kinetic energy of the projectiles as computed at 150 meters as computed by Kushnick and Duffy, the perceived dangerousness ratings read from Kushnick and Duffy's graph, and computed perceived dangerousness ratings obtained from the equation.

Table 3-2. Computed and Actual Perceived Dangerousness Ratings Based on Kinetic Energy

Weapon	KE x 10^{-8}	Actual PD	Computed PD
Caliber .50	28.00*	47	47.00
M60	3.63	41	40.97
AK 47	2.20	39	39.00
M16	1.33	37	35.99
Caliber .45	.93	27	23.01
XM 645	.94	23	26.97

*For ease in computation, 28.00 was substituted for the actual value of 27.97.

A correlation of $r = .96$ was obtained between the actual and the computed ratings. While a correlation of this magnitude is impressive, it must be remembered that the relationship was based on only six data points. Nevertheless, the psychological scale are means based on a large number of observations, and so should be relatively stable. Therefore, the result provides a reasonable indication that the perceived dangerousness of passing rounds, in the exact situation employed by Kushnick and Duffy, may be quite accurately predicted from a knowledge of the weight and velocity of the rounds.

Extrapolation of the curve obtained provides some interesting results. For example, the equation indicates that perceived dangerousness approaches 0 as KE x 10^{-8} approaches .927182. In other words, a projectile with a KE only very slightly less than the caliber .45 would be predicted to have virtually no value in suppression. Similarly, a 20mm weapon would be predicted to have a perceived dangerousness rating of 49, only very slightly better than the caliber .50. Therefore, the results indicate that it would probably not be logistically efficient to employ any larger weapons in suppression. However, it must be remembered that the predictions made would probably be applicable only in the exact situation employed in the Litton study. Furthermore, it is very possible that the actual shape of the curve is ogival. That is, at some point below a KE x 10^{-8} value of .93, the curve may turn toward the origin so that a KE of 0 would result in a 0 rating of perceived dangerousness. Since no data are available on projectiles with lesser KE than the caliber .45, the actual shape of the curve below this KE is indeterminate.

A similar attempt was made to fit a curve empirically to the data for the Suppression Index. The data on kinetic energy are the same as shown in Table 3-2 and the SI ratings were taken from Table 2-2. The equation derived is shown below.

$$SI = \frac{\ln\left[(x-a)/b\right]}{c}$$

where $x = KE \times 10^{-8}$

$a = .244383$
$b = .019885$
$c = .118728$

The correlation between the observed and computed values of SI is $r = .99$. Again, the fit is excellent. Employing this equation, it would be predicted that a weapon with a KE x 10^{-8} of .264268 or less would not be suppressive at all. Similarly, a 20mm weapon would be predicted to have an SI value of 69. A weapon which would totally suppress return fires (see Response C, Table 2-1, page 2-2) would have to have an SI of 80, and a KE x 10^{-8} of over 260. The use of such a weapon for suppression hardly seems practical, and the weapon would hardly be considered a small arm. Therefore, again, it seems that the caliber .50 weapon is probably the largest caliber weapon that should be employed in a purely suppressive capacity.

Although the mathematical models fitting the observed values of the psychological scales and kinetic energy were excellent, it must be remembered that only six data points were involved, and three of these were employed in the empirical process of curve fitting. Nevertheless, the fit to the remaining points cannot be ignored. Only the M16 rifle fails to fall almost perfectly on the curves, and the deviation in either case is probably of no practical significance. Therefore, it has to be concluded that any further research into this area should first look at KE as a variable in predicting psychological responses to weapons. If the results hold, it should not be necessary to look further at signature values of passing projectiles. KE may well take into account all critical aspects of the signature, at least for existing small arms. Of course, muzzle flash, muzzle blast, and impact signatures were not involved in the derivation of the equations, but, in circumstances where they are evident, will undoubtedly play a role in determining behavior.

The worth, valued against the cost, of doing further research in this area is a decision that must be reached by Army authorities. However, if further research is deemed to be warranted, it is recommended that the first step be an attempt to validate the usefulness of KE as the sole variable in predicting responses to passing projectiles. It is further recommended that a study of the relationship between KE and lethality be made, to assess the validity of the models which employ P_k (taking miss distance into account) as the primary determinant of suppression. Naturally, if possible, this effort should also consider blast, flash, and impact signatures singly and in combination with KE. All in all, such a program would be quite extensive in scope. As mentioned earlier, the desirability of such a program will have to be weighed against the desirability of other programs competing for limited funds. Nevertheless, the direction such a program should take, at least at first, seems clear.

Chapter 4

RECAPITULATION AND RECOMMENDATIONS

A primary purpose of this research was to determine, from information available, what aspects of the acoustic signatures of projectiles contribute to their being perceived as dangerous and/or result in suppressed behaviors. It was felt that no new data should be obtained at this time unless it could be shown that variation in the acoustic signatures of the various projectiles was indeed related to perceived dangerousness or suppressed behavior as reported by participants. Very little data on down range acoustic signatures could be found. However, such data would probably have not been useful in any case. Factors such as wind velocity and direction, temperature, humidity, vegetation, and distance from the muzzle have all been shown to affect at least some aspects of down range signatures. Therefore, unless all these conditions were knowns, data on acoustic signatures would probably not be of much value.

In further analysis of some previously reported data, kinetic energy, which is believed to be closely related to the perceived loudness of passing projectiles, appeared to account for nearly 100% of the variance between weapons in both a Suppression Index and a perceived dangerousness rating. Since kinetic energy at any given range from the muzzle can be computed relatively accurately from firing tables, this finding, if replicated, should prove useful in developing computer models involving suppression play. In the past, analysts have had to rely on intuition and/or fragmentary and possibly unreliable descriptions of battles and behavior under fire.

Although the use of kinetic energy appears to hold great promise for modeling suppression play, further research needs to be done. First of all, the general stability of equations derived needs to be determined. In other words, the results of the re-analysis reported in Chapter 3 need to be replicated. Moreover, additional work needs to be undertaken. The indices derived in the Litton studies were based on averages of ratings of several fire events. No means of partitioning the data to determine the effects of either miss distance or rate of fire on the scale scores is available. Additional work is needed to develop equations for various kinds of projectiles at various distances down range for each of several levels of miss distance and rate of fire. In addition, data on sound spectra, peak SPLs, and durations of the A and B waves should also be obtained. In the event that kinetic energy does not prove to be a reliable predictor of any scales employed such as the Suppression Index or the Perceived Dangerousness Index, an attempt could be made to relate these data to the scales derived.

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